Multistatic, Concurrent Detection, Classification and Localization Concepts for Autonomous, Shallow Water Mine Counter Measures

PI: Henrik Schmidt
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 5-204
Cambridge, MA 02139
Phone: (617) 253-5727 Fax: (617) 253-2350 Email: henrik@mit.edu

CoPI: Arjuna Balasuriya
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 5-204
Cambridge, MA 02139
Phone: (617) 324-1461 Fax: (617) 253-2350 Email: arjunab@mit.edu

Award Number: N00014-08-1-0011
http://lamss.mit.edu/lamss/pmwiki/pmwiki.php?n=Site.Projects

LONG-TERM GOALS

The objective of SWAMSI is the development and demonstration of robust multi-static detection and classification of proud- and buried seabed objects using cooperative networks of autonomous vehicles with acoustic sources and receiving arrays.

OBJECTIVES

The emphasis of the MIT SWAMSI effort has focused on utilizing high fidelity acoustic modeling of both scatterers and shallow-water environments to better understand and bound the limits of detectability for mine-like objects via autonomous networks of sensors, and the assess the performance of time-reversal processing for concurrent detection, classification, localization and Tracking (DCLT) of seabed objects. The analysis s supported by series of experiments using multiple sonar-equipped AUVs in shallow water and then cross-validate the results obtained with high precision modeling and visualization. Another, related objective is to better understand the problems of cooperative autonomous vehicle interaction to define the base-line infrastructure requirements for cooperative detection, classification and navigation, an understanding which may lead to guidelines for optimal collaborative configuration control of the underwater sonar platforms.

APPROACH

This program couples high accuracy acoustic modeling and visualization with customized AUV technology. The sonar sensing uses the bi-static and multi-static Synthetic Aperture created by the network, in combination with medium frequency (4-24 kHz) wide-beam insonification to provide

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Multistatic, Concurrent Detection, Classification and Localization Concepts for Autonomous, Shallow Water Mine Counter Measures**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology 77 Massachusetts Avenue Room 5-204 Cambridge, MA 02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

coverage, bottom penetration and location resolution for concurrent detection, localization and classification of proud and buried targets in SW and VSW. The signal processing effort in SWAMSI is therefore centered around generalizing SAS processing to bi-static and multi-static configurations, including bi-static generalizations of auto-focusing and track-before-detect (TBD) algorithms. Another issue concerns the stability and coherence of surface and seabed multiples and their potential use in advanced medium-frequency sonar concepts.

MIT's acoustic modeling capabilities derive from the OASES environmental acoustic modeling framework, which is a widely distributed suite of models covering a variety of ocean waveguide and source/receiver representations. Recent developments are computational modules for full wave theory modeling of mono-static and bi-static target scattering and reverberation in shallow water waveguides. The most recently developed module, OASES-3D provides wave-theory modeling of the full 3-D acoustic environment associated with mono-static and bi-static configurations in SW and VSW with aspect-dependent targets and reverberation features. It incorporates environmental acoustic features specifically associated with bi-static sonar concepts in shallow water, including aspect-dependent target models, seabed porosity, and scattering from anisotropic seabed roughness such as sand ripples.

With every major AUV deployment, the Mission Oriented Operating Suite (MOOS) previously created at MIT by research engineer Paul Newman advances in robustness and flexibility, and has been undergoing major upgrades in regard to the behavior-based control using the new IvP-Helm developed by Mike Benjamin, who in 2011 joined the MIT laboratory for Autonomous Marine Sensing Systems as Research Engineer, following a 20 year career at NUWC. Another significant component is the development of a comprehensive simulation testbed, coupling the MOOS-IvP autonomous vehicle simulation environment with a high-fidelity acoustic simulator, resulting in a complete, distributed software base for planning, simulating and analyzing multi-vehicle MCM missions.

WORK COMPLETED

Supervised Machine Learning for Underwater Target Classification

An increasingly important mission for Autonomous Underwater Vehicle (AUVs) is the identification and classification of potentially hazardous targets in harbors. To this end, a process has been developed in simulation to allow AUVs to classify underwater targets using only scattered acoustic amplitude data collected at selected waypoints. Target and bottom roughness scattered fields were simulated using OASES and SCATT, then combined and sampled into independent training and testing examples for a Support Vector Machine (SVM). The feature space and parameters for the SVM are selected using a design of experiments grid search. By processing the SVM model using a feature reduction algorithm, regions critical to classification within the scattered field are identified. To make use of the resulting models and critical features, a vehicle in the field would be loaded with per-generated models for bottom and target classification. When a target is localized, the vehicle would begin visiting the critical waypoints until a confident classification is achieved using the SVM models. The resulting in-flight classification, based only on amplitude data collected by a hydrophone along the vehicle's path, could be used as the basis for further action of the target. The same process used for classification was extended for regression of bottom anisotropy, allowing SVMs to be applied to continuous parts of the target characterization problem. This process could be broadly applied to a wide variety of target classification and regression problems, including shape, composition, size and orientation of targets.

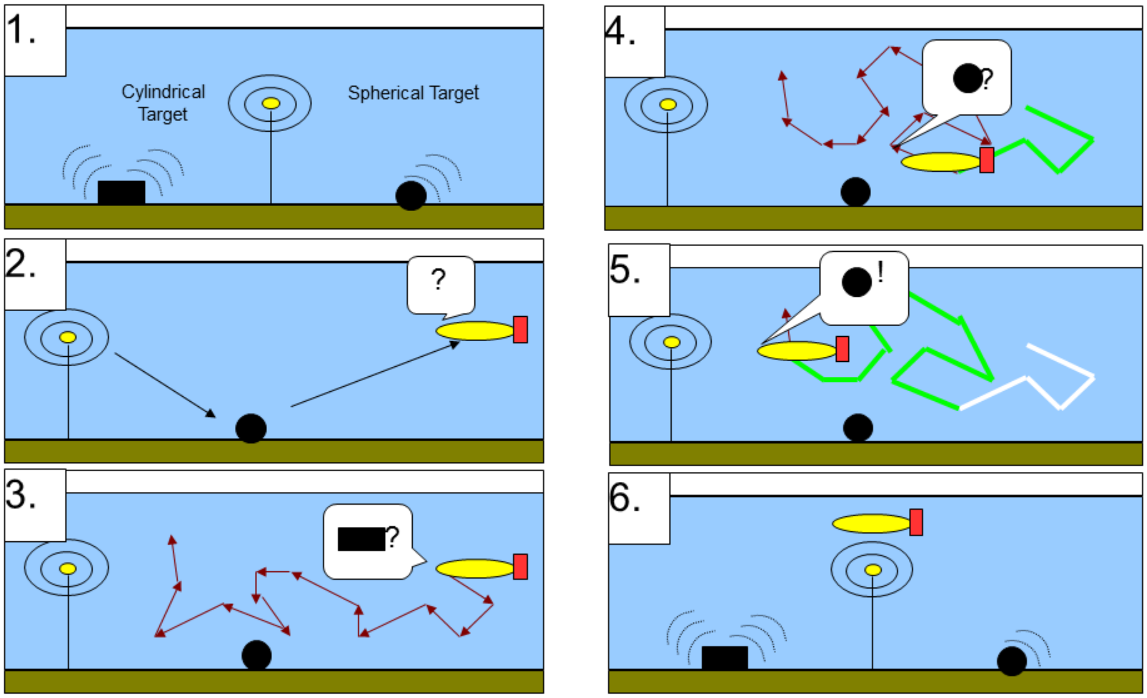

Figure 1.Final AUV behavior for bistatic classification with a fixed source: 1) Spherical and Cylindrical targets on the ocean bottom, with a fixed source between them. 2) An AUV enters the field, and find the first target acoustically.3) The AUV hypothesizes that the target is a cylinder, and charts an optimal path (using a* search and the known key waypoints from training) through the scattering field for a cylinder. 4) After completing the first few waypoints, the SVM classifications of the field are looking more like a sphere than a cylinder. The AUV changes its hypothesis to sphere. 5) After completing the majority of the sphere waypoints, the AUV has a sufficiently confident classification and returns its decision.

Acoustic Active Sonar Simulator Augmentation

The current acoustic active sonar simulator (capable of dealing with a deep ocean environment) has been further augmented to include a more accurate surface reverberation model developed by the Naval Research Laboratory. It has also been augmented to include the capability for various window functions to be added to both the source pulse as well as the overall sonar-beam. The simulator as also been expanded to take commands such as waveform type, elevation angle, and beam width from another module. The simulator can now handle calculating Doppler effects from a moving target as well as correct move-out over horizontal arrays, vertical arrays or a combination thereof). Along with all these improvements the entire simulator has been restructured and rewritten from the original MATLAB script to a faster C++ version. The C++ version is also more compatible with the MOOS (Mission Oriented Operating Suite) environment run on LAMSS' AUVS.

Underwater networking for AUVs

In 2012, we continued development of the second version of the Goby marine networking library and toolbox (Goby2). Goby2 is near final release stage and is mainly awaiting the completion of documentation. We have written new drivers allowing use of Iridium satellite communications, allowing a multi-hop network including both subsea (acoustic) and above water (satellite) links. Such

communications were successfully demonstrated at the Tiger12 sea trial involving a link from the research vessel to a deep sea mooring via two intermediate hops (one on shore, one on a waveglider). Figure 2shows a schematic of this setup.

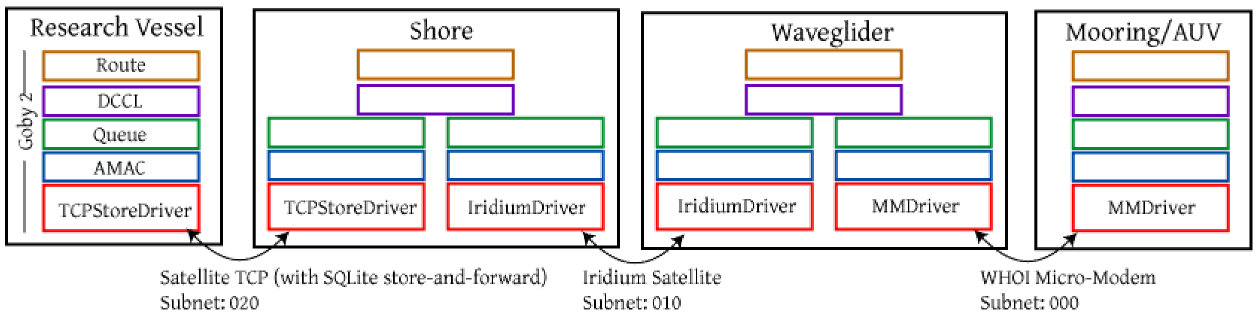

Figure 2.Structure diagram of the Goby components for the Tiger12 cruise to form a seamless link from the Research vessel to the Tiger mooring (and intermediate nodes) over a collection of different link types (satellite-TCP, satellite-Iridium, acoustic modem.[1]

Furthermore, we developed a scheme for very highly compressed telemetry of AUV position based on differential entropy encoding of projected future positions. The prior sent positions of the AUV are used to extrapolate the future position. The difference from this extrapolated position and the actual future position is sent which is used by the receiver to decode the new position. This difference (or error) can be well modeled by a center-weighted probability distribution and is thus suitable for near-optimal encoding using an arithmetic source encoder. Such an encoder was written for Goby2, and the results of running it on the GLINT10 AUV Unicorn dataset is given in Fig. 3. This figure is a histogram which shows the number of messages from the dataset with a given encoded size (in bits, where smaller is better) for each of three different models plus an uncompressed baseline (int32). As this figure shows, this technique provides compression of up to 90% (in the adaptive model case) more than the uncompressed message (int32). Furthermore, the adaptive model provides 86% more compression than the widely used Compact Control Language, a marshalling scheme that is widely used in the field and that this work aims to replace.

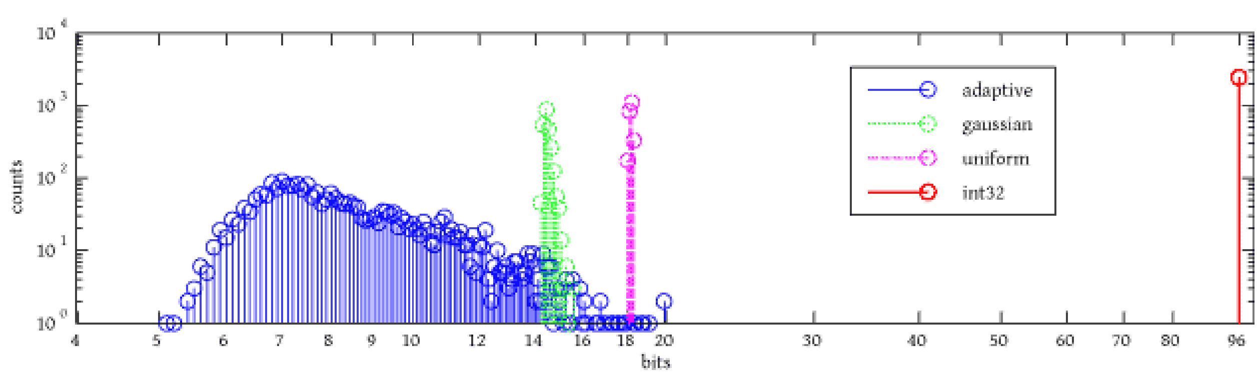

Figure 3.Histogram of all messages' size in bits to send AUV's x,y,z position to a resolution of 1 meter every 10 seconds from the GLINT10 dataset. Note that the adaptive model (generated from prior statistics) performs the best after a certain learning period. The "int32" is an uncompressed comparison. [2]

RESULTS

Supervised Machine Learning for Underwater Target Classification

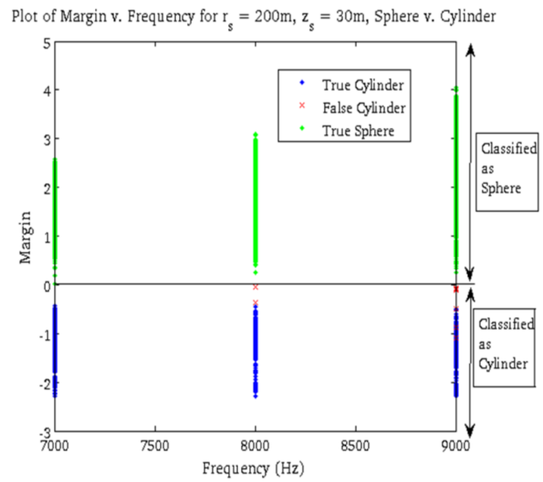

Figure 4. Plot of margins verses frequency for spherical verses cylindrical targets, indicating true and false classifications.

The basic elements of this SVM target classification approach have been demonstrated using simulated data from SCATT and OASES acoustic packages. Scattered fields were generated for fluid filled spherical and cylindrical targets of varying dimensions in the presence of isotropic or anisotropic rough bottom interference. SVM training examples were then generated by inputting scattered amplitudes along AUV "paths" consisting of sets of randomly generated waypoints. Independent test examples were used to test the model robustness. The results for a SVM test classification of target shape for a sphere verses cylinder case, with isotropic rough bottom scattering, can be seen in figure 4, which shows margin verses frequency for a data set including 25-waypoint long AUV paths. After SVM classification is run on all of the random test examples, the model is assessed based on the true positive to false positive and true negative to false negative margin ratios. A large ratio implies that a high margin implies correct classification for both spherical and cylindrical targets.

For example, the model testing shown in figure 4 indicates that the strongest negative classifications (cylinders classified as cylinders) can be clearly distinguished from the worst false positives (spheres classified as cylinders) just based on margin. There are no paths that classified cylinders as spheres in this test set. The highest margin paths were algorithmically reduced to isolate key features within the region between the source and target. The paths that result from this algorithmic path reduction are therefore able to classify the targets with high confidence using only 20-30 waypoints.

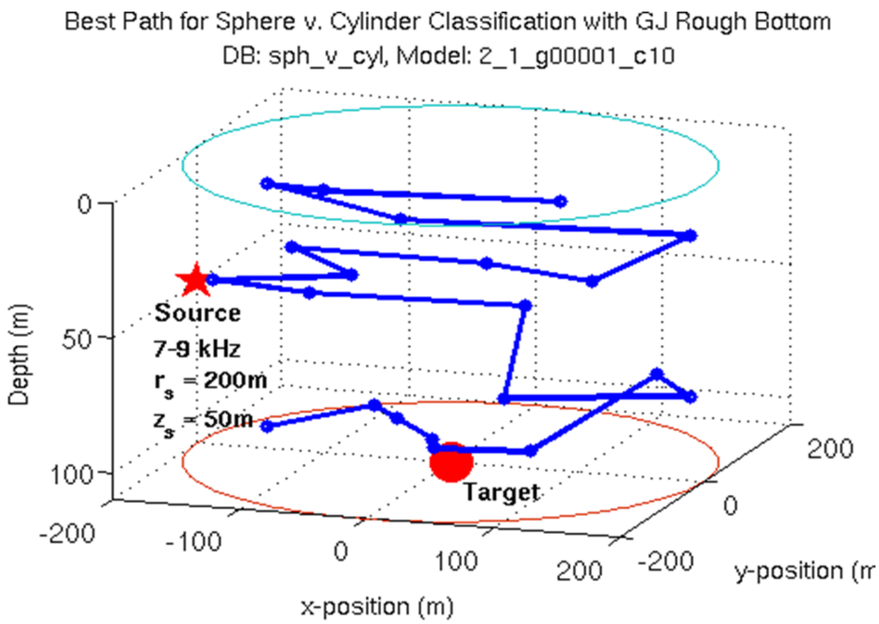

Figure 5. Plot of the best path of 25 waypoints for the classification of spherical verses cylindrical targets at all frequencies.

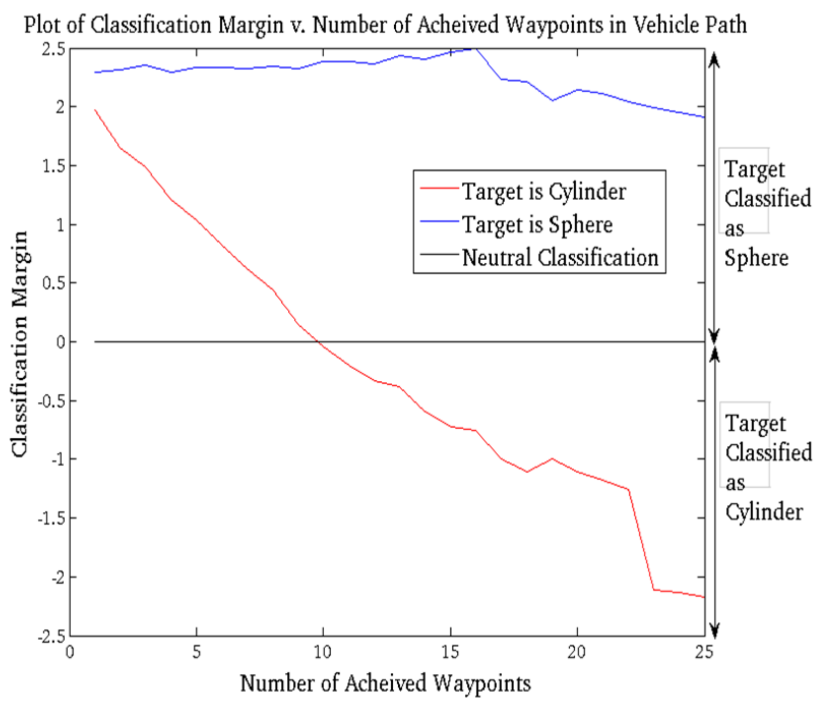

Figure 6. Plot of margin verses number of waypoints visited by a vehicle following the path shown in figure 6 through the scattered fields around spherical and cylindrical targets.

The best 25 waypoint path from this test set is then selected, and a path planning algorithm, such as an a* search, is applied to the waypoint set to choose a vehicle's path for best classification. The best path for source range = 200m, source depth=50m, and frequency=7-9kHz is shown in figure 5. Figure 6 shows the classified margin verses number of waypoints achieved along this best path by a simulated AUV as it passes through simulated spherical and cylindrical scattered fields. A positive margin indicates a spherical classification and a negative margin indicates negative classification. Both spheres and cylinders are correctly classified by the model with high confidence as an AUV completes the path through the fields.

IMPACT/APPLICATIONS

The long-term impact of this effort is the development of new sonar concepts for VSW MCM, which take optimum advantage of mobility, autonomy and adaptivity. For example, bi-static and multi-static, medium-frequency sonar configurations are being explored for completely or partially proud or buried mines in shallow water, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and its environment.

TRANSITIONS

The virtual source modeling approach developed under this project has been transitioned to NURC (now CMRE) as part of the OASE3D target modeling framework. Here it has been coupled to the COMSOL finite element framework to allow modeling of complex elastic targets. It has also been transitioned to NUWC (J. Blottman), CSS (D. Burnett), and WSU (Marston) for the same purpose.

There are several other ONR and NSF sponsored distributed sensing programs applying the MOOS-IvP payload autonomy architecture develolpoed by MIT-LAMSS under GOATS and SWAMSI, including PLUSNet and UCCI. Most recently the autonomy system has been adopted by the DARPA Deep Sea Operations Program (DSOP). The active sonar simulation environment developed under SWAMSI has also been transitioned to the DSOP program, where it has been modified to a deep ocean active sonar environment. Outside the US, MOOS-IvP is being adopted by DSTO in Australia, and continues to be used and further developed by the Nato Undersea Research Centre, now CMRE.

The Goby software infrastructure for underwater networking for AUVs, developed under SWAMSI and GOATS, has continued to see significant growth in 2012, including outside the MOOS-IvP community, quickly becoming a *de-facto* standard for underwater networking on fielded vehicles. Bluefin Robotics is adopting the Goby2 Dynamic Compact Control Language (DCCL) as their subsea messaging scheme, the Ocean Observatories Initiative is adopting Goby2 for AUV communications, and research groups from institutions including the University of New Brunswick, MIT, the University of Washington, and the Georgia Tech Research Institute have been adopting Goby for their AUV projects.

RELATED PROJECTS

The research effort under this Grant is a seamless continuation of the effort carried out under Grant N00014-04-1-0014. Sharing the underwater vehicles and autonomy system, this effort is closely related to the GOATS project, initiated as the GOATS'2000 Joint Research Project (JRP) with the NATO Undersea Research Centre (NURC). The GOATS effort has been continued at MIT under the

GOATS'2005 grant (N00014-05-1-0255), funded jointly by ONR codes 321OA, 321OE, and 321TS. The effort is currently continued under the ONR program GOATS 2008 - Autonomous, Adaptive Multistatic Acoustic Sensing (N00014-11-1-0097) including funding for the collaboration with NURC, which continues under a Joint Research Projects (JRP) on multistatic acoustic sensing and surveillance, and undersea distributed sensing networks.

The continued development and maintenance of the MOOS-IvP autonomy software being funded by ONR Code 31 (D. Wagner and B. Kamger-Parsi, Program Managers), as well as Non-Government Institutions such as Battelle Memorial Institute.

PUBLICATIONS

1. T. Schneider and H. Schmidt, "Goby-Acomms version 2: extensible marshalling, queuing, and link layer interfacing for acoustic telemetry," in *Proceedings of the 9th IFAC Conference on Manuevering and Control of Marine Craft*, Arenzano (GE), Italy, 2012.

2. T. Schneider and H. Schmidt, "Approaches to Improving Acoustic Communications on Autonomous Mobile Marine Platforms," in *Proceedings of the UComms 2012 Conference*, Sestri Levante (GE), Italy, 2012.

3. F.B. Jensen, W.A. Kuperman, M.B. Porter and H. Schmidt, "Computational Ocean Acoustics", 2nd edition, Springer, New York, 2011.

4. T. Schneider and H. Schmidt, "Model-based Adaptive Behavior Framework for Optimal Acoustic Communication and Sensing by Marine Robots", *IEEE J. Oceanic Eng., In Press* (2012).

5. R. Lum and H. Schmidt, "Integrated Perception, Modeling and Control for Bistatic Sonar Tracking by Autonomous Underwater Vehicles", Submitted to *IEEE J. Oceanic Eng.,* (2012).